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MOBILE ATOMIC GRAVITY GRADIOMETER PROTOTYPE INSTRUMENT (MAGGPI)

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Final Report

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During the one year of active development, Yale established subprograms to develop four key instrument systems. They were (1) field-ready laser systems (involving the design and construction of a ruggedized, portable laser system), (2) control electronics systems (developed the digital and analog electronics systems required to control each accelerometer sensor), (3) UHV vacuum system (developed prototype ultra-high vacuum systems based on all-glass sealing techniques and (4) platform motion simulation and control. For the latter, Yale evaluated the vibration environment in several candidate motion platforms. It also determined the specs for a suitable six-degree of freedom motion actuation system and developed a system concept and requirements for platform stabilization and control to achieve the required vibration environment for sensor operation. The detailed work related to each of these four instrument systems will not be present. The Principal Investigator accepted a position at Stanford University. A new contract will be started there and the effort will continue.

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<u>Summary of Accomplishments During Active Period of Contract</u>

During the one year of active development, Yale established sub-programs to develop 4 key instrument systems. They were (1) field-ready laser systems (involving the design and construction of a ruggedized, portable laser system), (2) control electronics systems (developed the digital and analog electronics systems required to control each accelerometer sensor), (3) UHV vacuum system (developed prototype ultra-high vacuum systems based on all-glass sealing techniques) and (4) Platform motion simulation and control. For the latter, Yale evaluated the vibration environment on several candidate motion platforms. It also determined the specs for a suitable six-degree of freedom motion actuation system and developed a system concept and requirements for platform stabilization and control to achieve the required vibration environment for sensor operation. The detailed work related to each of these 4 instrument systems will now be presented. *The Principal Investigator accepted a position at Stanford University and a new contract will be started there and the effort will continue.*

<u>Field-ready laser systems:</u> A slave laser module was developed. It contains eight high-power semiconductor lasers for use in a master-slave configuration. For each slave laser, light from a master is brought into the system through a single-mode polarization preserving optical fiber, after which it is fed into the facet of an SDL laser running at 852 nm. In this configuration, the output light from the slave is frequency matched to the frequency of the input beam, with an additional frequency offset provided by a double-passed acousto-optic modulator (AOM). The AOM is also used to control the intensity of the output laser field. In the design and construction of this frame, Yale evaluated slave lasers from competing suppliers before selecting the SDL model. In order to improve injection locking reliability, Yale had the laser facets anti-reflection coated and applied a beam circularizing micro-lens to the laser output. The final lens shapes the mode into a circular Gaussian and enables high efficiency coupling into an optical fiber. An independent electronics subsystem provides the required high stability current and temperature regulation to the lasers.

<u>Control electronics system</u>: Electronics development focused on two sub-systems: the high stability temperature and current controllers required to drive the semi-conductor lasers and the digital/mixed signal electronics required to control the overall function of the sensors. A laser current and temperature controller were used to drive the semi-conductor lasers. Yale evaluated commercial and in-house controller designs before settling on an in-house design that showed substantially improved current noise performance. Commercially off the shelf temperature controllers from Wavelength Electronics were adequate for the overall design.

For the digital/mixed signal control electronics, Yale evaluated hard real-time control solutions based on PC104/Intel CPU and TI DSP architectures, before selecting the TI DSP solution. Initial performance tests indicated much greater hardware/software stability and lower timing jitter for the DSP based system. Innovative Integration was identified as the prime vendor for DSP cards due to the availability of high channel

density (16 analog), intermediate speed (100 Ks/sec) daughter cards. The system core is built around a single C6711 SBC card. Code is written in C and the interface to the DSP is via TI's Code Composer Studio v.2. Agile RF control is accomplished using digital output from the C6711 to control compact Novatech DDS cards. It was verified that Novatech DDS has adequate phase-noise characteristics for the contract's relatively demanding application. In-house digital interface cards are used to coordinate control signals between the DDS and controlling DSP host.

Vacuum systems: Yale developed in-house all glass sealing techniques. These techniques were also used to demonstrate exceptional mechanical stability – performing significantly better than optical contact seals. Specialized techniques were developed yielding ultra high vacuum compatible seals for Zerodur and Quartz. Two prototype chambers were developed using this technique during the first performance year.

Platform simulation and control: Yale initiated a program to identify promising platform actuation techniques, and to acquire information on the vibration environment of candidate platforms. Its platform actuation analysis had two focuses: to accurately simulate the vibrational environment of candidate vehicle platforms and to develop a strategy for controlling the orientation of the actual survey system. As these two work areas are tightly linked, groundwork was laid for detailed design work for both.

Field platform vibration/rotation data was acquired for three candidate platforms: UHU1 Helicopter, Bell 206 Helicopter, and a Chevrolet Suburban. Data were acquired with a pair of Crossbow IMU's to ensure measurement integrity and several high bandwidth Crossbow accelerometers. A detailed analysis of all vibration records was performed providing key inputs into the design and specification of the six degree of freedom motion base needed for this contract.

A survey of available commercial motion-base solutions was performed as well as an evaluation of platform performance with respect to what was identified as the key performance requirements: Position, velocity, acceleration dynamic range and motion actuation bandwidth. The relatively large amplitude acceleration noise at high frequency induced by the rotor motion presents a stringent constraint which rules out many commonly used actuator types. A performance study was commissioned to specifically evaluate these high frequency performance characteristics. The study, carried out by Parallel Robotics, a manufacturer of hexapod based machining systems, indicated that achieving large amplitude low frequency motion plus high frequency rotor motion would be difficult to achieve with commonly used actuators. As a result, the Yale team has sought to identify breakthrough actuator technologies that will enable faithful simulation of a broad range of motion environments. The team identified a servo-ram linear motion actuator that is likely capable of meeting these requirements.

In addition to a full simulation of platform motion, the effort also requires a motion-base to simulate the less demanding motion environment present at the sensor itself. The characteristics of this environment will be determined by the 6 degree of freedom vibration isolation system (to be designed and tested in the 3rd and 4th year of the effort at

Stanford U.) and are benign in comparison to the raw motion environments of the host vehicle. Yale identified a commercial supplier for this platform. The MaxCue motion system the team ordered will enable the first sensor performance studies in mid FY03 at Stanford U.